**Workshop**

**Advanced Simulations:**

**A Critical Tool for Future Nuclear Fuel Cycles**

# Material Simulation Needs

# For Advanced Reactors

**Bill Halsey (LLNL)**

**Livermore, CA**

**12/15/2005**

National Nuclear Security Administration
Department of Energy • University of California
Science in the National Interest
Lawrence Livermore
National Laboratory

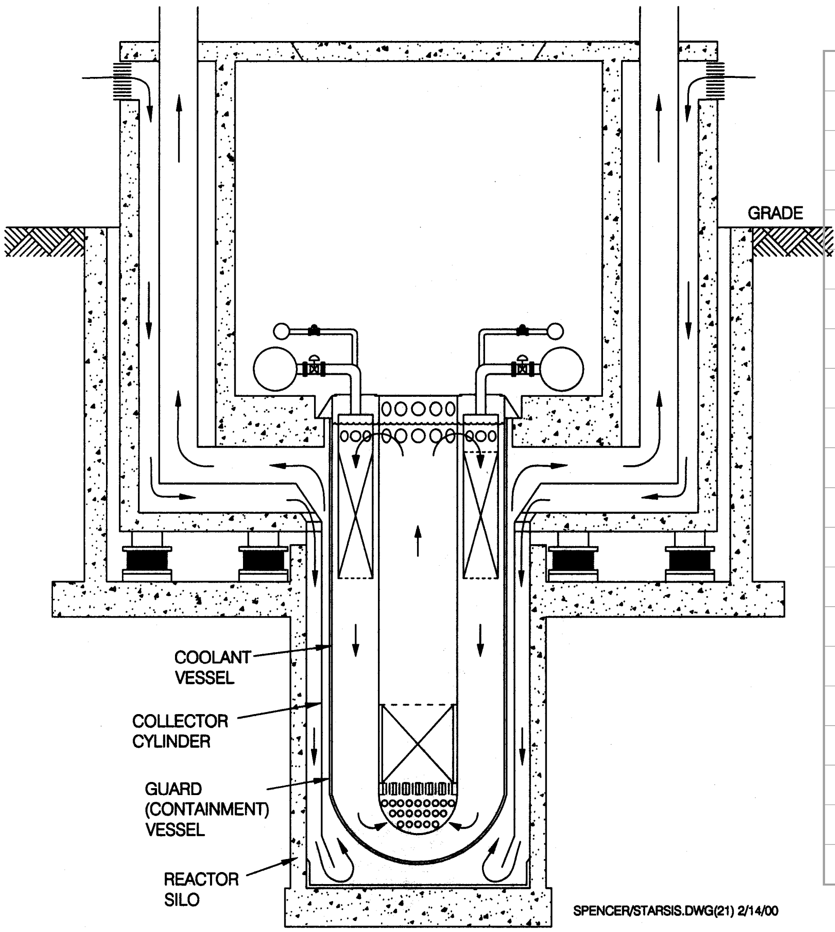
# Why Do We Need Advanced Materials Simulations?

- **We don't need advanced simulations to deploy Gen-III LWRs:**
  - Certified, demonstrated and ready to go
- **We don't need advanced simulations to build reactors:**
  - SFR - Dozens built, some 50 years ago
  - LFR - Half-dozen over decades
  - HTGR - Several of several designs, decades
  - MSR - 40 years ago
  - SCWR, GFR - no demo, but not because of material models
- **We don't need advanced simulations to license reactors:**
  - Hundreds licensed globally, dozens of designs
  - NRC processes for advanced reactors, LBT, …

# Why Do We Need Advanced Materials Simulations?

- **We need advanced simulations to make advanced reactors more competitive:**
  - Push temperature, fluence, and stress beyond experience
- **We need advanced simulations to make advanced reactors more reliable:**
  - Long lifetime, minimal maintenance, high reliability
- **We need advanced simulations to make advanced reactors more flexible:**
  - Wider range of operating conditions, load following, multi-mission,…
- **We need advanced simulations to save time and money:**
  - Concurrent, parallel design/optimization of materials and reactors
  - Concurrent, parallel testing and model development
    - Understand what we measure, predict beyond what we can measure, and design experiments fo understand further

# Example: Current Den-IV SSTAR LFR Point-design: 20 Mwe, 20 year core (ANL design)




**STAR-LM Features**

| | |
|---|---|
| Core Diameter, m | 1.02 |
| Active Core Height, m | 0.8 |
| Nitride Fuel Smeared Density, % | 85 |
| Fuel Volume Fraction | 0.55 |
| Cladding Volume Fraction | 0.16 |
| Bond Volume Fraction | 0.10 |
| Coolant Volume Fraction | 0.16 |
| Fuel Pin Diameter, cm | 2.7 |
| Fuel Pin Pitch-to-Diameter Ratio | 1.096 |
| Cladding Thickness, mm | 1.0 |
| Average Power Density, W/cm$^3$ | 69 |
| Specific Power, KW/Kg HM | 10 |
| Peak Power Density, W/cm$^3$ | 119 |
| Average Discharge Burn up, MWd/Kg HM | 72 |
| Peak Discharge Burn up, MWd/Kg HM | 120 |
| Peak Fast Fluence, n/cm$^2$ | $4.0 \times 10^{23}$ |
| BOC to EOC Burn up Swing, % delta rho | 0.13 |
| Maximum Burn up Swing, % delta rho | 0.36 |
| Estimated Delayed Neutron Fraction | 0.00375 |
| BOC to EOC burn up Swing, $ | 0.35 |
| Maximum Burn up Swing, $ | 0.96 |
| | |

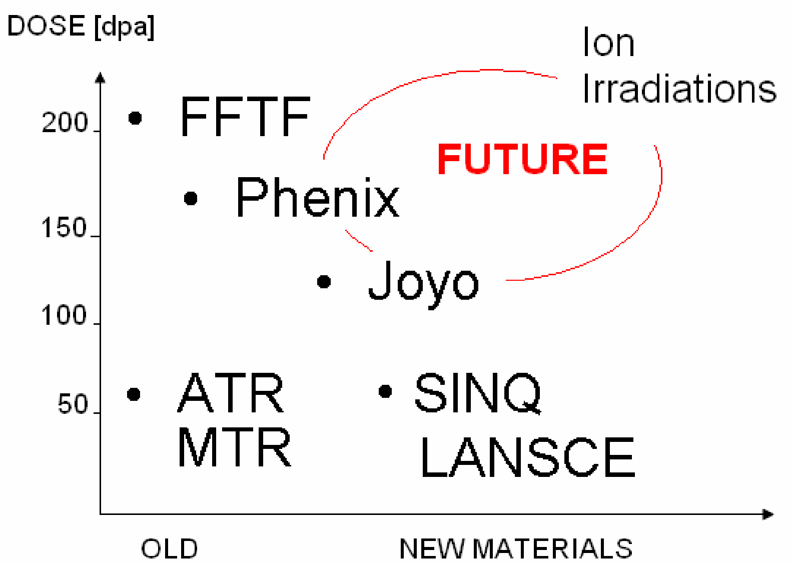
# Materials Issues

- **Both Pb and LBE are challenging corrosion environments**
  - Oxygen Control:
- **Temperature drives the material options**
  - Known materials may work up to 500 - 550C
  - Evolutionary or new materials needed for desired performance (550-650C)
- **High fast neutron fluences complicate the issue**
  - Design is constrained by $4x10^{23}$ $n/cm^2$ limit
- **Simple, long-core-life adds unique demands**
  - Corrosion life, creep, thermal alteration
  - High reliability required (limited inspection, full core replacement, …)
- **Low pressure system gives some relief on stress**

*Advanced Simulations can help with many of these issues.*

# Example: LFR Fast Neutron Fluence

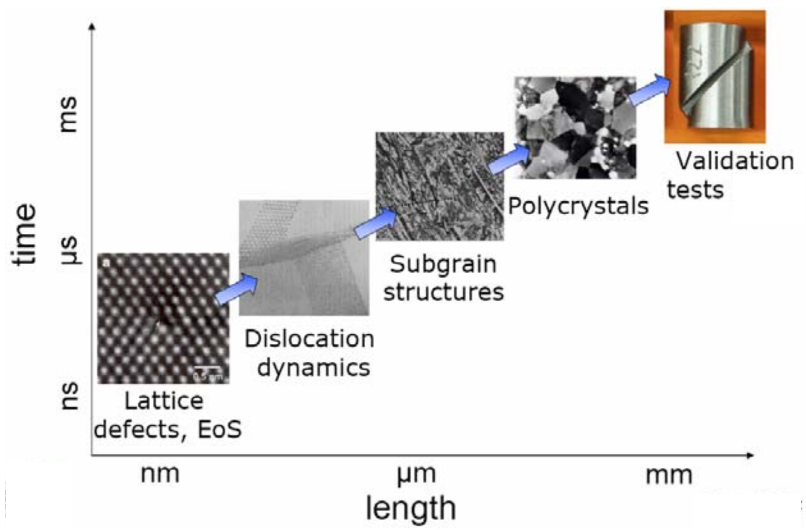
- **We have experimental data for materials that are not optimized for Pb corrosion**
  - HT-9 to 4X10$^{23}$ n/cm$^2$/s
  - T-91, MA957, …
- **Evolutionary materials for Pb service:**
  - Si and/or Al enhanced, ODS, …
  - Radiation trade-off (Cr vs Si, …)
- **We can only test with non-representative conditions**
  - Ion irradiations to high dose
  - Fast neutrons to low/medium fluence, limited temp, no Pb




***We need sufficient models to extrapolate***

# Materials Simulations Must Bridge Basic Science to Applied Engineering

- Design Feedback
  - Temp/Stress/Time/Fluence
    - Thermal creep
    - Irradiation creep
    - Swelling
    - Fracture toughness
- Material Design
  - Composition/Treatment - Bulk/Surface
- Test Planning and Analysis
  - Understanding/Prediction/ Optimization
- Materials Qualification
  - Testing/modeling/standards/ regulation




***Simulations are $10^7$-$10^8$ & 5-10 years from these abilities. However, testing is $10^8$-$10^9$ and 10-30 years from these answers.***

***Challenge: what can simulations provide to design 'along the way' ?***